U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.
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NOTES

ON

A NEW METHOD

FOR THE DISCUSSION OF

MAGNETIC OBSERVATIONS.

BY

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., July 8, 1892.

SIR: I have the honor to submit herewith a paper entitled "Notes on a New Method for the Discussion of Magnetic Observations," which has been prepared by Prof. Frank H. Bigelow, of this Bureau, and to recommend its publication as Weather Bureau Bulletin No. 2.

Very respectfully,

MARK W. HARRINGTON,
Chief of Weather Bureau.

Hon. J. M. RUSK,
Secretary of Agriculture.

TABLE OF CONTENTS.

NOTES ON A NEW METHOD FOR THE DISCUSSION OF MAGNETIC OBSERVATIONS.

I.—INTRODUCTION.

The object of this Bulletin is to describe a new method of dealing with the observations of magnetic observatories, particularly such as use photographic traces for automatic records. In seeking to extract the meaning from these curves, for the development of certain terms which seem to occur in meteorology and in other branches of science, it was found necessary to adopt certain principles and devices which prove to have a practical value.

It is not primarily intended in this paper to develop in a complete form any of the conclusions to which we may ultimately come, but it has been found simpler to employ them in an example which illustrates the analysis of the observations. Hence the reader will keep in mind that the justification of any apparently unsupported statements may be looked for in other publications which are to follow this, and in such papers a reference will be made to this Bulletin for an explanation of the treatment of the data. It will be seen that, incidentally, some suggestions have been made regarding certain questions that have received the attention of magneticians.

In order to view the subject in its proper proportions it will be necessary to recall the main steps in a somewhat extended investigation, of which this forms only one stage. Broadly, the science of terrestrial magnetism divides itself into two parts, the first being concerned with the origin and conditions of the so-called permanent magnetism of the earth, including the asymmetric distributions and the secular variations of the same; the second dealing with the variations and the disturbances of the magnetic needle. Our own work has been confined almost exclusively to the second portion of the problem.

There are well-known mathematical discussions of the general problem which conclude that the larger part of the observed terrestrial magnetic field must be derived from sources within the surface of the earth, while a small part comes from regions outside this surface; in a word, that the permanent magnetism originates within, and the periodic variations without, the surface of the earth. The question then arises regarding the variations, whether they are caused by corresponding changes in the physical conditions of the atmosphere, or whether they are produced by cosmical influences emanating for the most part from the sun and the moon. At this place we interpose the remark, that the position is regarded as proven that the sun and the

moon do not continuously influence the terrestrial field by direct action as magnets, in the inverse proportion of the cube of the distances, such action being without doubt inappreciable.

There have been two general lines of hypotheses regarding the variations, one in which they are referred to atmospheric fluctuations responding to the astronomical relations existing between the sun, moon, and earth; the other, by which they are supposed to arise from the electro-magnetic relations between the earth and the ether in which it rotates.

The first step in the method now to be presented was a discussion of the solar corona, deriving the material from the photographs of the corona during the eclipses of July 29, 1878, January 1 and December 22, 1889, these being the only ones available, so far as known, in which the filamentary structure of the rays is shown with sufficient clearness to admit of the measures that are required to illustrate the theory.

A preliminary paper[1] was published in October, 1889, wherein was developed the mathematical treatment of the subject, and a first approximation in a comparison of the observations with the theory was appended, the theory being that the solar corona exhibits the action of some force conforming to the law of the Newtonian potential in the case of repulsion. No attempt has been made to ascribe this force to a specific physical agency, though it is evident that it resembles closely the action of electricity and magnetism. This view was further developed in various papers,[2] with the following special results, the localization of the coronal poles upon the sun, the period of rotation of the same, the restriction of the bases of the visible coronal streamers to a narrow belt about ten degrees in width, the central line being about thirty-four degrees from the coronal poles.

The point at which this subject touches terrestrial magnetism consists in the recognition of the fact that the law of the coronal streamers is such that, when applied to the whole of the field about the sun, there must be some invisible stream lines, which emanating from the polar regions of the sun, after sweeping wide through space, in the region of the orbit of the earth, are at right angles to the plane of the ecliptic. For lack of a better mode to express our conception, we may speak of the ether in the region of the earth as strained perpendicularly to the plane of the ecliptic.

Working upon this fundamental idea that the ether may be strained in certain directions, in response to directive influences emanating

[1] The Solar Corona, Discussed by Spherical Harmonics: Smithsonian Institution, Washington, D. C., 1889.

[2] Further Study of the Solar Corona: American Journal of Science, November, 1890.—The Solar Corona, an Instance of the Newtonian Potential Function in the case of Repulsion: American Journal of Science, July, 1891.—The Law of the Solar Corona: Publications of the Astronomical Society of the Pacific, November 14, 1891.—The Rotation Period of the Sun at Latitude 85°.5: Publications of the Astronomical Society of the Pacific, November 16, 1891.

from proper sources, we proceeded by assuming that the ether in the neighborhood of the earth was actually in such a condition of strain in three directions at right angles to each other, first, radially in the direction of the sun, second, perpendicular to the ecliptic, and third, along the line of the orbit; the final justification of these premises to depend upon the relation they bear to the observed quantities, inasmuch as there is little known to science that could suggest them by the *à priori* method.

Some of the logical consequences of this theory were developed very briefly, especially in their application to terrestrial magnetism, in two other papers.[3] It is one of the purposes of this paper to illustrate the fact that we possess definite evidence of the existence of these primary directed influences or fields, as they may be called. They are named the radiant field, the coronal field, and the orbit field.

The next inquiry was, what effect has the atmosphere and the rotation of the earth upon these fields; or, how do these uniform fields act in the region of the earth, considered as a spherical conductor, surrounded by a concentric spherical conducting shell of variable specific conductivity? If the earth were a homogeneous spherical conductor placed in a uniform field or a series of fields, and rotating while being translated through them, the problem, though complex, is analytically soluble; but the conditions not being simple it became of prime importance to discuss the modifications of the simple law introduced by the ever varying state of the atmosphere considered as a conducting medium. Hence the question had to be settled whether meteorology has anything to do with terrestrial magnetism or not.

As regards this great problem to which we have drawn attention, what we present at this time is preliminary, but it is also enough to strengthen the main lines of the theory, and by so doing promises much encouragement for work of this kind. It is hoped that the development of the case will not lead to any permanent difficulties that cannot be overcome, for the following reason—in a final analysis it appears that all these phenomena are probably to be referred to Newton's law. On its positive side this gives rise to gravitational phenomena, and on its negative side to electrical or magnetic phenomena. Since the elder branch of the science has been so faithful to the facts of nature, we may expect that the other will be equally comprehensive in its range and simplicity.

II.—THE DEFLECTING FIELDS.

The guiding idea that has been employed in the investigation is as follows: Surrounding the earth at any instant of time is a given magnetic field, or a field traversed by lines of magnetic force, which dif-

[3] Bulletin No. 18 of the U. S. Scientific Expedition to West Africa: May 15, 1890.—Note on the Causes of the Variations of the Magnetic Needle: American Journal of Science, September, 1891.

fers from some primary or normal field by certain distortions. These changes from the geometrical type, referred to the suitable ideal premises, are produced by deflecting forces which are due to magnetic tensions. It classifies the conception to inquire how many of these deflecting forces, or how many fields of deflection, can be detected, and when we speak of fields, from this point onward, we wish to be understood as meaning the directions along which the deflecting forces act, no matter to what causes in nature they are to be ascribed.

We therefore enumerate the following deflecting fields, supposed to be known as—

I. Distributing the magnetism within the surface of the earth:
1. The field perpendicular to the ecliptic.
2. The field parallel to the axis of rotation of the earth.
3. The asymmetric fields, due to the water and land areas of the crust of the earth, and the non-homogeneous structure of its interior.

II. Periodically disturbing the general field produced by those just mentioned:
4. The annual deflection.
5. The diurnal deflection.
6. The lunar deflection.
7. The solar deflection.

III. Spasmodically disturbing the field:
8. The meteorological disturbance.
9. Disturbances, directed
(*a*) towards the sun;
(*b*) perpendicular to the plane of the ecliptic;
(*c*) along the orbit of the earth; all directions are to be taken as only approximately described.

We will limit the scope of this paper to the deflections 4, 5, 8, and 9.

THE ANNUAL DEFLECTION.

Since the earth, according to our view, is a conductor polarized in certain directions, which may be regarded as those of the observed poles of permanent magnetism at any epoch, and is placed in the above-mentioned uniform fields, the specific angles of entry and departure of the lines which are bent from the direction of the undisturbed uniform field into the directions induced by the presence of a spherical conductor in the uniform field depend upon the angle existing between the axis of polarization and the axis of the uniform field. Now, by the annual revolution of the earth about the sun this angle changes in the period of a year, and gives rise to the annual deflecting field.

THE DIURNAL DEFLECTION.

Of the three uniform fields at right angles to each other, the radiant field is usually much stronger than the others, in fact always so except during intervals of specific disturbance. This field is actually parallel to the plane of the ecliptic, positive in the direction of the sun, but in consequence of this diurnal rotation of the earth, in accordance with the mathematical principles developed (Bulletin No. 18, see note [3]), the field is apparently retarded through an angle depending upon the velocity of rotation and the specific conductivity of the earth. This angle appears conspicuously in our results, and has a value of about twenty-three degrees for the northern hemisphere. Since the magnetic poles of the earth do not coincide with its axis of rotation, the angular relations of the conductor as polarized are continuously changing, in respect to the field, in a period of twenty-four hours, and this causes the diurnal deflection.

At this stage of the development it would be mere speculation to attempt to inquire into the physical relations between this magnetic field and the sun's radiations. That there is such a connection appears to be substantiated by the computations. Electricity and magnetism have many common properties; that electricity and light are intimately associated appears also to be the outcome of scientific discovery; and now we have the third bond exhibited between magnetism and solar radiation. Hence it will not be going too far to presume that electricity, magnetism, and light are all manifestations of the activity of the ether. In fact all space, and all the matter in space, seems to be stressed through and through by directed influences, to which we give various names in the physical sciences. The importance of following up this connection between magnetism and sunlight is apparent.

THE METEOROLOGICAL DISTURBANCES.

It was seen, early in our study of the curves or traces produced by the magnetic instruments, that an elimination of the annual, the diurnal, and also the disturbance fields, would not fully account for the facts that were therein exhibited. There was a persistent and conspicuous swaying up and down of the traces of the horizontal, the declination, and the vertical curves, which seemed to be wholly independent of the periodic curves and even of the marked disturbances, inasmuch as this swaying property, relative to the base-line, was as manifest on quiet as on disturbed days.

As a probable explanation of this fact we assumed that it was due to changes in the conducting capacity of the dielectric, or conditions of the spherical conducting shell surrounding the earth, that is, to the atmosphere, and that hence it was strictly a meteorological phenomenon associated with the passage of the high and low centers near

the station of observation. If solar radiations are transmuted into magnetic forces at the earth, these fluctuations in the condition of the atmosphere which change the radiant effect of the sun will likewise alter the amount and direction of the resulting magnetic force at any point. What these physical conditions are still remains to be investigated. It will be possible in this Bulletin only to indicate the method of research.

THE DIRECTED DISTURBANCES.

The same method of treatment enables us to detect those directions in space from which the disturbances come to the earth, and from the discussion of all the important disturbances during four months of 1889 it is clearly seen that they are strictly confined to three directions, as stated above in (*a*), (*b*), and (*c*). The stronger the disturbances the more persistently they follow these directions; at certain parts of the field there is evidently a conflict of forces which produces a varying resultant; but these places of conflict only serve to heighten the contrast whenever the fields are acting simply by themselves. The field (*a*), directed along the radiant field, as modified by the lag produced by rotation, is clearly due to the radiations of the sun; the field (*b*), perpendicular to the ecliptic, is perhaps due to the spasmodic coronal action of the sun; the field (*c*), directed some degrees westward of that part of space to which the earth is moving, also shows the same lag angle as field (*a*); it appears on the dark side of the earth, and may be due to some type of induction not as yet clearly analyzed.

I now proceed to a brief description of the mode of treating the observations, giving a simple example of the same by way of illustration.

III.—THE COÖRDINATES AND FORMULÆ.

It is proposed to obtain residual ordinates to the horizontal force, the declination, and the vertical force, which will be applicable respectively to the fields that have been described. For the variation of ordinates measured on the curves is in reality an integration of the combined effect of all the fields acting simultaneously. We assume a system of rectangular coördinates,

X, positive north in the plane of the horizon of the station, and in the plane of the mean magnetic meridian of the year;

Y, positive west and perpendicular to X, and also in the plane of the horizon;

Z, positive downwards along the normal perpendicular to the plane of the horizon.

Hence the magnetic azimuth is counted in the direction N, W, S, E, and for magnetic altitude + means that the force acts beneath the plane of the horizon, and —, that it acts above it.

If we take ΔH, the uncorrected residual for the horizontal force, ΔD, the uncorrected residual for declination, and ΔV, the uncorrected residual for the vertical force, we can compute a value corresponding to them, dx, dy, dz, from which will be obtained,

$\sigma = \sqrt{dx^2 + dy^2}$, the component of the total deflecting force on the horizontal plane.

$s = \sqrt{dx^2 + dy^2 + dz^2}$, the total deflecting force acting in space.

$\tan \beta = \frac{dy}{dx}$, where β is the azimuth of the deflecting force.

$\tan \alpha = \frac{dz}{\sigma}$, where α is the altitude of the same.

The labor of computing σ, s, α, β by squares or logarithms is so great, in view of the large amount of such work needed, that a diagram scale was constructed which practically reduces the time required to one-fourth of that by the first method, the accuracy being easily within one unit.

On a card is drawn a square 10.8 inches on the side, in which is inscribed a circle divided into half degrees, and numbered on each degree. The radius is divided into 200 units. The surface of the large square is subdivided into small squares, the sides of which are one-twentieth of the radius; also a series of concentric circles, whose radii differ by the same amount, is spread over the area; and radii are drawn in for every tenth degree, extending from the fifth to the twentieth circle. All the quadrants are numbered fully, so as to render it easy to plot in a point whose coördinates are given. For numbers up to about 200 the scale admits of direct use; for larger numbers the coördinates are reduced by a convenient factor, the final linear dimension being restored by this factor, the angle, of course, being the same in either case. Practically, one enters dx, dy, and reads off σ β directly; reënters σ, dz, and reads off s, α. Using a stylus and estimating by the eye, the results flow very rapidly from it.

The change of ΔH, ΔD, ΔV, to dx, dy, and dz, requires some explanation. The coördinates are chosen so that a positive value of these residuals indicates an increase of force in the positive direction of these axes. If the ordinates are taken directly from the photographic traces some reductions are necessary before they are available. The instrumental values must be reduced for the temperature coefficient in the case of ΔH and ΔV, the temperature not affecting ΔD. The values of ΔH, ΔV, in terms of millimeters, must be transposed to the corresponding values of the absolute force, as determined by a set of instruments for this purpose, and the coefficient of the value of one millimeter in terms of absolute force for H and V must be known. Since ΔD is an angle it must be translated into a corresponding W

and E force. Now the mean horizontal force for the year, H_0, may be taken as the base of a triangle of which the altitude is determined by the angle ΔD, hence $dy = H_0 \tan \Delta D$. An auxiliary table may be constructed for any station, as has been done for Washington, by means of which the change can be effected at a glance from the value of ΔD in minutes of arc to the W — E deflecting component dy.

I will say that all the results obtained have been wholly corrected for the temperature of the magnet, and that no objection can properly be interposed into my discussion on that account. As far as possible I have used the reduced final values of the instruments as they appear in the publications of the U. S. Magnetic Observatory for the years 1889 and 1890 (from advanced sheets) and 1891 (from manuscript). I take the opportunity to acknowledge the obligations that the Bureau is under to the courtesy of the Navy Department, especially to Commodore George Dewey, Chief of the Bureau of Equipment, to Captain F. V. McNair, Superintendent of the U. S. Naval Observatory, and to Ensign J. A. Hoogewerff, U. S. N., in charge of the U. S. Magnetic Observatory, whereby it has been possible to undertake this work. In the case of other observatories it has been necessary to depend upon the results appearing in the volumes containing their reports. As has been seen, the two important elements of transposition are the temperature coefficient and the value of one millimeter ordinate in terms of the absolute force. It is precisely these to which Ensign Hoogewerff has paid the closest attention, and the rigid scrutiny to which it has been necessary to submit the curves and the reduced values, seems to justify us in placing confidence in the efficiency of the work he has done.

THE TREATMENT OF THE OBSERVATIONS.

As a starting point in the analysis of these residuals, we take the annual mean value of the H, D, V; that is, the mean derived from the twenty-four observations for each day, summed for each day, and again summed for the whole year. The range of 365 days is broken up into the usual twelve monthly groups, by summing for the respective days of the month. Subtracting the mean of the year from the mean for the month, we obtain the residuals pertaining to the annual curve. By plotting these and running smooth curves through them, the annual deflection at the individual day is secured.

If we take the means by months for each of the twenty-four hours and subtract from them the mean of the month, we obtain the mean residuals of the diurnal curve for the month. In passing from month to month we could also construct average curves, one for each of the twenty-four hours, by which could be obtained the diurnal curve for any specified day, but this refinement of calculation has not been attempted.

The question next arises as to the proper dealing with days of

marked disturbance, one that continues to puzzle magneticians. I have, in the use of observations, restricted myself to the striking out of not more than one in ten of the extreme values, obtained by reading the ordinates of the curves for the hours, just as they occurred, even if upon the crest or the bottom of a disturbance. When we are seeking a normal curve this is evidently incorrect, limiting the ordinates to twenty-four points, and it could be improved only by using a very large number of such points, or practically integrating the area included between the curve and the base line. As this is hardly practicable, I shall take the opportunity further along in this paper of suggesting a device for accomplishing something better than the 24-point method.

If, again, we subtract the mean of the month from the mean of the twenty-four hours for each day, we obtain what I regard as the meteorological element in the problem, this residual being the mean amount by which the diurnal curve for the day lies above or below the mean diurnal curve, except so far as affected by the ordinates of marked disturbances, which of course ought to be eliminated, and which are partially compensated by the average of the disturbance flux and reflux for the day. This meteorological residual is the mean for the day, but, properly, it should be distributed through the day, unless it is intended to make a comparison between the mean of the magnetic-meteorological residuals, and the meteorological variations as disclosed by the instruments for the mean of the day. I shall show, however, a way in which this residual can be distributed along the day, and then comparisons can be made with the meteorological elements for any specified hour.

Finally, if from the actual ordinates for any moment the total deviations accounted for up to this point, that is, the annual plus the diurnal plus the meteorological residuals, be subtracted, we shall have the residual of the disturbance proper, and this apparently exhausts the problem. It remains, therefore, to explain how we have endeavored, practically, to separate these residuals. The example is taken from the volume of the Washington observations, 1886, Appendix I, entitled "Magnetic Observations at the U. S. Naval Observatory, 1888–1889," and we select the month of March as an average case. It should be said that the computations were made before the relation with the meteorological elements was investigated, and that no changes have been made in the figures as here reproduced. A tabular presentation of the computations is introduced from time to time, which will be easily understood from the arrangement and the adjacent line of thought.

TABLE I.—*Horizontal*

The figures given in the table are millionths of a dyne, which added

.198000+

Day.	A. M.											
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1	405	409	687	767	739	768	782	617	618	599	693	670
2	712	735	749	735	807	736	764	745	709	662	620	605
3	802	826	816	807	803	831	794	714	687	649	602	611
4	846	813	775	808	837	851	837	861	815	862	867	805
5	874	846	855	851	847	889	885	814	773	806	857	890
6	894	1017	819	866	820	703	905	698	628	206	586	652
7	853	708	567	708	680	685	798	821	705	710	705	611
8	802	943	797	821	817	841	826	794	719	644	649	649
9	789	813	836	789	837	828	832	771	702	683	674	683
10	847	856	861	861	885	857	843	815	858	722	637	651
11	842	828	847	861	862	881	876	843	774	774	779	713
12	1041	980	928	975	986	939	925	896	855	860	794	752
13	812	859	765	878	808	874	931	982	889	885	856	833
14	785	781	781	795	833	805	796	749	717	707	674	684
15	795	814	833	856	852	866	843	740	708	661	914	679
16	824	839	881	848	848	871	867	792	759	698	688	669
17	868	849	863	896	877	849	882	830	727	623	713	825
18	596	615	620	714	718	690	596	526	526	521	577	......
19	776	804	799	813	827	837	813	780	729	710	691	691
20	786	819	805	819	814	838	791	781	735	617	565	655
21	768	862	815	825	834	834	834	754	726	693	651	552
22	953	901	713	661	798	774	802	760	708	567	572	581
23	761	780	846	789	799	761	756	799	728	662	695	761
24	800	879	832	832	851	738	785	814	795	781	677	649
25	768	744	768	805	[illegible]	[illegible]	772	711	716	763	739	697
26	863	816	830	830	830	820	830	797	736	712	712	750
27	713	765	737	732	788	774	784	680	619	718	788	793
28	451	587	587	559	677	695	498	818	625	545	503	498
29	701	790	701	701	711	743	772	645	518	452	438	368
30	730	796	796	806	801	782	796	735	650	500	486	509
31	830	807	830	802	778	816	807	727	609	557	595	628
Mean..	783	803	785	800	811	805	807	768	712	663	679	670

force, *March*, 1889.

to .198000 dyne, give the absolute horizontal force in C. G. S. units.

.198000+

Day.	P. M.												Mean.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	
1	610	563	699	699	794	738	747	757	706	678	729	729	675
2	658	691	550	696	786	824	819	786	782	782	792	787	731
3	655	772	871	833	858	839	839	839	849	779	798	845	780
4	830	821	882	900	939	930	925	831	846	832	818	921	852
5	858	896	915	967	935	1015	968	953	743	419	541	658	836
6	653	488	653	761	814	814	786	804	801	772	707	594	727
7	668	654	664	800	707	655	829	853	802	778	882	755	733
8	739	913	927	847	797	768	768	815	802	816	807	793	796
9	689	717	773	825	845	859	864	845	865	879	851	851	796
10	667	690	775	840	856	865	870	856	852	861	857	838	813
11	845	892	939	902	908	926	922	922	913	890	866	866	861
12	790	880	983	1007	904	636	730	918	919	872	863	849	887
13	857	872	716	669	638	741	652	595	507	671	671	624	774
14	755	779	784	812	836	813	747	799	828	833	800	889	783
15	690	798	727	831	851	860	888	884	842	828	838	828	809
16	787	853	890	876	857	829	806	857	881	890	900	895	829
17	835	821	1206	835	445	—185	149	—039	356	426	454	595	658
18	662	714	784	841	855	831	850	855	826	737	714	789	702
19	701	771	799	827	823	715	818	809	809	804	846	804	783
20	702	725	739	739	706	810	749	777	758	739	711	753	747
21	585	731	717	712	811	717	820	839	829	858	938	905	775
22	605	732	793	760	647	624	628	671	713	802	779	773	722
23	799	803	817	831	822	836	860	869	836	822	822	784	793
24	743	800	847	879	922	818	832	842	785	724	738	842	800
25	749	782	848	843	815	801	[illegible]	805	815	796	815	824	781
26	900	947	924	900	858	830	708	731	722	698	......	......	806
27	962	793	864	915	925	859	864	835	751	605	976	643	787
28	822	493	757	719	738	808	686	677	719	719	639	625	644
29	725	762	767	711	762	711	795	814	823	828	837	847	705
30	524	538	608	688	768	754	782	796	810	796	801	806	711
31	633	741	830	835	811	816	821	830	830	816	783	797	764
Mean..	726	756	808	816	808	770	784	788	785	769	786	784	769

TABLE II.—*Declination*,

Ordinates, expressed in minutes of arc, taken from the daily declination traces.
declination at

Base-line value

Day.	A. M. 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
	′	′	′	′	′	′	′	′	′	′	′	′
1	64.2	68.1	68.4	67.6	68.2	69.1	71.6*	77.4*	71.4*	72.0*	69.0	70.5
2	68.2	67.4	67.7	67.3	67.6	69.6	69.0	67.0	66.3	68.1	69.9	72.1
3	69.0	69.9	70.4	68.4	67.5	67.8	67.4	67.0	66.4	67.0	68.9	70.4
4	68.7	67.6	67.1	67.1	67.0	66.9	68.0	65.7	66.0	67.8	68.9	70.7
5	67.7	69.0	67.1	67.9	69.1	67.4	67.3	66.8	67.5	67.8	68.4	69.8
6	70.2	66.3	64.2*	67.1	73.5*	72.0*	69.1	71.0*	71.6*	75.5*	74.6*	....
7	66.6	66.8	70.1	68.4	69.2	69.4	68.0	66.4	66.6	67.8	67.7	69.6
8	68.4	71.1	71.1	68.1	68.1	68.4	68.1	67.0	68.0	67.9	69.9	72.3
9	68.9	69.0	69.8	69.0	69.0	68.6	68.0	67.0	66.7	67.7	69.4	....
10	69.2	68.9	68.7	68.6	68.2	68.9	68.4	66.4	66.0	66.2	68.0	70.2
11	69.0	69.2	68.2	68.2	68.4	68.4	68.1	67.1	67.4	67.8	69.1	....
12	68.6	66.9	67.0	67.0	66.5	67.9	67.5	66.9	65.4	67.0	68.2	70.0
13	68.1	69.1	68.4	68.2	68.2	68.1	67.6	67.3	66.2	66.0	67.7	69.3
14	69.0	68.3	68.3	68.8	68.6	68.6	68.0	67.3	67.2	67.7	69.2	71.4
15	69.1	69.1	68.8	68.3	67.8	68.0	66.1	66.2	65.2	66.6	69.5	71.0
16	67.7	72.1*	68.3	67.7	67.8	68.0	67.0	67.0	66.7	67.7	70.2	71.6
17	68.2	68.1	68.0	68.0	67.5	67.9	66.1	64.3	64.4	66.2	69.8	71.7
18	67.1	68.2	68.0	68.5	69.0	68.0	65.9	64.7	65.2	....	69.9	....
19	69.0	68.9	68.3	68.1	68.0	67.3	66.3	65.0	64.9	65.9	67.8	69.9
20	68.4	68.8	68.1	68.0	67.6	68.0	66.3	65.7	65.6	65.5	68.0	69.9
21	69.8	68.8	68.3	68.9	68.6	68.4	67.1	66.6	67.1	66.8	68.7	72.0
22	66.3	64.0*	67.2	64.3*	65.6*	65.9*	65.5	65.2	66.0	66.1	69.5	71.6
23	68.7	68.6	70.0	68.2	68.1	68.0	68.0	67.4	66.6	66.5	68.4	69.7
24	68.8	68.2	68.1	68.0	67.2	69.1	70.9	67.6	67.0	67.6	69.1	70.8
25	66.2	68.3	67.5	67.9	67.0	68.1	67.0	66.7	67.1	67.2	68.8	70.7
26	69.1	68.5	67.9	67.9	67.6	67.6	67.1	66.2	65.8	66.2	68.8	72.1
27	67.6	68.0	68.1	68.2	68.1	67.0	66.1	65.4	66.0	66.4	69.2	71.0
28	60.3*	68.8	64.4*	67.4	68.8	66.7	66.0	69.4*	64.0	66.0	70.1	75.0*
29	68.4	69.2	68.7	68.7	68.8	67.6	65.1	64.5	66.4	66.4	69.9	74.4*
30	68.4	70.3	67.2	66.1	68.2	68.8	66.7	64.5	64.9	65.8	67.4	68.8
31	69.2	68.9	68.8	69.5	70.1	68.2	66.9	65.0	65.1	65.9	68.2	71.4
Mean..	68.3	68.7	68.4	68.0	68.0	68.1	67.3	66.3	66.1	66.8	68.9	70.7

March, 1889.

The ordinate for any hour added to the base-line value gives the absolute westerly that hour.

$= 2° 51' 31''$

Day.	P. M.												Mean.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	
	′	′	′	′	′	′	′	′	′	′	′	′	
1	74.0	75.7*	73.2	70.3	69.0	68.9	68.7	68.5	68.7	69.9	69.1	69.3	70.01
2	73.2	74.0	73.6	71.5	69.9	69.3	68.9	68.8	68.9	68.9	69.0	69.2	69.39
3	72.3	72.5	72.4	71.3	70.3	69.6	69.3	69.1	69.3	69.0	69.6	70.3	69.38
4	71.7	71.8	71.4	70.3	69.6	69.5	69.1	68.9	68.9	69.0	68.7	68.6	68.71
5	70.7	70.9	70.5	69.8	69.9	70.3	69.9	69.2	69.5	64.0*	66.1	66.0	68.44
6	72.6	72.6	71.1	70.6	69.9	69.1	68.6	67.7	68.1	67.1	65.9	64.4*	69.69
7	71.1	72.0	72.3	70.8	70.1	68.9	69.0	68.9	68.6	67.2	65.7	68.7	68.75
8	73.1	72.5	72.1	70.7	70.2	69.5	69.0	68.6	67.6	66.2	68.7	69.0	69.40
9	72.4	72.7	71.9	70.8	69.7	69.4	69.2	69 0	69.0	68.9	69.1	69.1	69.32
10	71.8	72.1	72.9	71.9	69.7	69.2	69.1	69.0	69.3	69.0	69.0	68.6	69.07
11	70.5	71.1	71.3	71.3	72.1	71.7	70.0	69.2	69.1	68.7	68.4	68.5	69.14
12	70.9	71.0	70.3	69.5	69.5	69.6	69.3	69.0	69.0	68.3	68.7	68.5	68.44
13	71.2	71.9	73.1	77.0*	72.9	73.2*	73.3*	73.0*	70.0	63.5*	68.5	68.9	69.61
14	73.2	72.1	71.9	71.1	70.1	69.9	69.0	69.0	69.0	68.5	67.4	68.4	69.25
15	72.3	73.3	73.0	70.7	69.7	69.4	69.0	68.7	68.8	69.0	69.7	67.8	69.05
16	72.2	72.6	72.3	70.9	69.6	68.6	68.3	68.6	68.5	68.7	68.6	68.5	69.13
17	74.1	73.1	74.1	73.5	73.9	71.0	72.0	71.8	68.0	66.9	71.2*	63.8*	69.32
18	72.0	72.1	72.0	71.0	70.0	69.3	69.0	68.9	68.7	67.0	68.7	67.3	68.66
19	71.8	72.5	72.1	71.6	70.6	69.6	69.2	68.7	68.8	64.9	67.3	69.0	68.56
20	71.6	72.7	73.5	73.1	73.4	70.8	70.5	69.2	69.0	67.8	69.1	69.0	69.15
21	73.9	74.4	75.2*	74.0	72.0	70.6	69.9	68.8	69.5	69.1	68.8	68.9	69.84
22	72.9	72.1	73.4	71.8	71.9	70.9	63.5*	68.9	70.2	69.4	68.9	68.8	68.33
23	70.8	71.0	70.7	70.4	69.7	69.4	69.2	68.9	69.0	68.8	69.3	68.7	68.92
24	71.1	71.5	71.4	71.0	70.4	70.4	69.8	69.6	69.8	68.3	69.9	71.0	69.44
25	71.0	71.3	71.7	70.4	70.0	69.7	69.7	69.1	69.2	69.1	69.0	68.9	68.82
26	71.8	70.8	71.4	70.8	70.5	70.2	68.9	66.8	68.6	68.3	......	......	68.77
27	71.6	72.5	72.4	71.4	70.5	70.6	70.1	70.7	64.9*	66.3	57.4*	65.6	68.55
28	73.6	75.9*	72.2	73.2	71.2	69.7	69.9	66.3	65.2*	67.5	68.4	68.4	68.68
29	74.3	73.6	73.9	72.6	70.4	68.5	69.6	69.4	69.2	69.3	67.2	68.2	69.35
30	70.5	71.8	72.4	71.8	70.6	69.5	69.1	68.6	69.0	68.9	68.9	69.0	68.63
31	73.4	74.5	74.6	73.0	71.1	70.3	69.6	69.3	68.9	69.0	69.0	68.9	69.53
Mean ..	72.2	72.3	72.2	71.3	70.3	69.8	69.4	68.9	69.0	68.2	68.5	68.6	69.08

TABLE III.—*Vertical*

The figures given in the table are millionths of a dyne, which,

.581000+

Day.	A. M.											
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1	163	221	237	242	238	229	197	187	183	170	156	104
2	243	230	202	236	241	242	248	248	240	212	165	122
3	223	200	186	191	192	203	204	185	138	115	092	111
4	270	266	286	291	301	298	299	279	261	257	254	249
5	259	260	280	280	281	263	269	254	255	261	248	238
6	339	206	183	279	208	151	200	243	259	284	290	266
7	156	109	177	321	312	318	353	357	349	350	308	274
8	399	371	344	363	383	403	428	428	410	377	306	268
9	355	351	342	352	353	359	360	355	342	309	238	214
10	358	364	365	370	371	372	387	373	355	303	260	246
11	352	349	350	354	365	366	372	372	344	326	312	312
12	303	319	329	334	345	350	342	327	309	267	230	186
13	230	193	179	155	161	162	182	187	188	179	176	176
14	229	273	279	274	280	295	301	301	302	293	304	323
15	271	272	273	273	279	289	305	295	301	292	264	245
16	246	247	243	267	273	283	299	279	280	267	230	225
17	244	245	246	246	247	244	259	249	198	122	118	118
18	306	283	284	284	261	242	267	258	225	159	126	150
19	199	209	220	225	226	241	247	237	210	187	149	144
20	246	251	252	252	258	274	289	265	252	248	215	206
21	273	249	249	254	254	259	259	249	220	196	139	124
22	259	196	134	187	244	288	321	326	321	249	192	201
23	278	254	230	230	240	249	254	259	259	206	163	163
24	168	163	163	158	158	148	134	115	124	100	086	091
25	206	230	230	230	235	249	225	225	211	144	110	115
26	115	115	120	120	120	129	139	139	134	048	(—)005	019
27	249	196	163	153	168	168	172	129	072	028	028	033
28	(—)226	(—)039	(—)068	(—)024	(—)015	014	(—)005	014	028	(—)048	(—)111	(—)087
29	206	177	201	216	225	240	225	206	182	124	100	086
30	139	134	134	163	177	196	206	201	196	182	192	206
31	244	240	240	240	235	244	249	249	240	177	144	110
Mean ..	236	230	228	262	246	251	258	251	238	216	177	172

force, March, 1889.

added to .581000 dyne, give the vertical force in C. G. S. units.

.581000 +

Day.	P. M.												Mean.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	
1	191	254	284	294	271	257	263	278	303	284	281	271	232
2	132	157	153	197	202	242	257	257	253	250	230	236	216
3	217	228	267	287	288	279	299	304	305	306	312	297	226
4	235	212	223	228	234	230	235	255	261	276	282	258	260
5	297	336	313	284	295	305	316	330	384	428	429	381	302
6	295	344	384	374	370	357	358	377	373	355	342	323	298
7	294	310	354	359	374	370	371	386	391	407	408	393	325
8	303	337	362	333	349	350	360	351	357	353	359	354	360
9	253	259	270	284	300	296	306	330	341	347	348	348	317
10	295	325	336	302	308	309	310	320	335	336	347	342	333
11	333	329	315	311	307	308	318	357	387	383	355	321	342
12	202	227	242	276	301	331	317	288	270	262	258	248	286
13	201	230	270	327	324	334	330	378	427	337	338	357	251
14	295	292	259	259	284	290	281	267	258	269	260	246	280
15	261	262	272	282	283	284	294	304	300	316	297	254	282
16	221	222	228	252	243	249	250	264	261	257	263	301	256
17	100	158	222	260	434	757	690	762	610	529	429	314	325
18	204	196	206	206	212	227	200	195	201	226	179	198	221
19	126	137	133	181	206	221	237	251	262	253	254	245	209
20	173	188	233	257	291	292	293	284	280	290	291	287	257
21	134	153	192	216	249	268	278	292	297	302	307	302	238
22	259	278	307	331	364	360	355	350	336	326	312	288	283
23	177	192	206	211	187	192	158	158	153	158	168	168	205
24	139	172	177	196	211	182	240	201	216	230	244	230	165
25	153	148	134	134	139	134	115	120	115	115	115	120	165
26	067	072	096	076	096	110	110	129	124	144	......	....	101
27	024	033	038	048	057	086	067	081	091	100	000	(—)125	086
28	110	168	321	244	244	249	240	283	230	225	220	220	091
29	129	153	168	177	192	196	182	177	177	177	177	144	177
30	249	216	225	192	211	249	249	235	254	264	273	268	209
31	100	086	139	196	216	211	201	187	187	177	172	163	194
Mean ..	199	215	236	244	259	275	274	283	282	280	275	258	243

Regarding the means of H, D, V, it should be remarked that those given in the report for H and V were adopted unchanged, but since took the means out for D, I had the opportunity to reject a few of the outstanding disturbance ordinates, and it would be better to do likewise in the cases of H and V. The original means for D were derived from measures on the composite curves, but it is now thought best not to continue that system of treating the observations.

The result of this computation is not very instructive on the face of of it, because it represents the integrated deflecting force arising from the change in the permanent magnetism of the earth at Washington for 1889, and the periodic term arising from the motion of the earth around the sun. As soon as the secular variation can be discovered by itself, or on the other hand the annual deflection obtained by itself, then the other term can be treated, a process which it may be hoped can be accomplished in due time.

TABLE IV.—*The annual deflection curve for the year* 1889.

Month.	H	D	V	ΔH	ΔD	ΔV	dx	dy	dz	σ	s	a	β
		° ′			′							°	°
January	.198934	3 59.24	.581789	+221	—1.71	+1337	+221	—99	+1337	244	1354	+80	336
February	.198827	3 59.96	.581374	+114	—0.99	+ 922	+114	—58	+ 922	129	931	+83	334
March.............	.198769	4 0.60	.581243	+ 56	—0.35	+ 741	+ 56	—20	+ 791	60	794	+85	340
April..............	.198740	4 1.51	.580913	+ 27	+0.56	+ 461	+ 27	+33	+ 461	43	463	+86	49
May	.198678	4 1.60	.580521	— 35	+0.65	+ 69	— 35	+38	+ 69	53	87	+53	132
June...............	.198638	4 0.75	.580134	— 75	—0.20	— 318	— 75	—12	— 318	75	327	—76	189
July	.198605	4 0.64	.579532	—108	—0.31	— 920	—108	—18	— 920	110	927	—84	190
August	.198745	4 1.35	.579860	+ 32	+0.40	— 592	+ 32	+23	— 592	38	593	—87	34
September	.198655	4 1.68	.579927	— 58	+0.73	— 525	— 58	+42	— 525	72	530	—83	145
October...........	.198655	4 1.04	.580231	— 58	+0.09	— 221	— 58	+ 5	— 221	59	230	—75	175
November	.198630	4 1.24	.579723	— 83	+0.29	— 729	— 83	+17	— 729	85	734	—83	168
December.........	.198678	4 1.83	.580174	— 35	+0.88	— 278	— 35	+51	— 278	62	285	—77	125
	.198713	4 0.95	.580452										

TABLE V.—*The diurnal deflecting curve for the month of March, 1889.*

	H	D	V	ΔH	ΔD	ΔV	dx	dy	dz	σ	s	a	β
		° ′			′							°	°
		2 51.52											
Midnight ...	.198784	+, 68.57	.581258	+ 15	—0.51	+15	+ 15	— 30	+15	34	36	+23	297
1	783	68.27	236	+ 14	—0.81	— 7	+ 14	— 47	— 7	50	51	— 8	286
2	803	68.70	230	+ 34	—0.38	—13	+ 34	— 22	—13	39	41	—15	327
3	785	68.36	228	+ 16	—0.72	—15	+ 16	— 41	—15	44	46	—18	292
4	800	68.05	262	+ 31	—1.03	+20	+ 31	— 60	+20	67	70	+16	297
5	811	68.00	246	+ 42	—1.08	+ 3	+ 42	— 63	+ 3	76	76	+ 2	303
6	805	68.13	251	+ 36	—0.95	+ 8	+ 36	— 55	+ 8	66	67	+ 7	304
7	807	67.29	258	+ 38	—1.79	+13	+ 38	—104	+13	111	112	+ 6	291
8	768	66.30	251	— 1	—2.78	+ 8	— 1	—161	+ 8	161	162	+ 3	269
9	712	66.06	238	— 57	—3.02	— 5	— 57	—174	— 5	183	183	— 2	252
10	663	66.84	216	—106	—2.24	—27	—106	—130	—27	168	172	— 9	232
11	679	68.92	177	— 90	—0.16	—66	— 90	— 9	—66	91	113	—36	186
Noon	670	70.74	172	— 99	+1.66	—71	— 99	+ 96	—71	138	156	—28	136
1	726	72.25	199	— 43	+3.17	—44	— 43	+183	—44	187	193	—13	103
2	756	72.30	215	— 13	+3.22	—28	— 13	+186	—28	187	191	— 9	94
3	808	72.24	236	+ 39	+3.16	— 7	+ 39	+183	— 7	188	189	— 2	78
4	816	71.34	244	+ 47	+2.26	+ 1	+ 47	+131	+ 1	140	140	+ 1	70
5	808	70.32	259	+ 39	+1.24	+16	+ 39	+ 72	+16	81	83	+12	61
6	770	69.78	275	+ 1	+0.70	+32	+ 1	+ 40	+32	40	52	+38	91
7	784	69.40	274	+ 15	+0.32	+31	+ 15	+ 18	+31	25	40	+52	53
8	788	68.94	283	+ 19	—0.14	+40	+ 19	— 8	+40	21	46	+62	339
9	785	68.97	282	+ 16	—0.11	+49	+ 16	— 7	+49	18	53	+70	340
10	769	68.20	280	0	—0.88	+37	0	— 51	+37	51	63	+36	269
11	786	68.46	275	+ 17	—0.62	+32	+ 17	— 36	+32	40	51	+39	296
Midnight ...	784	68.57	258	+ 15	—0.51	+15	+ 15	— 30	+15	34	36	+23	297
	.198769	69.08	.581243										

IV.—MODEL SHOWING THE DIURNAL DEFLECTIONS.

In order to bring out visibly the meaning of our results s, α, β, we constructed a model in the following way. A rubber ball about 10 inches in diameter is surrounded by meridian lines, one for each hour. Instead of revolving the ball upon its axis, the magnetic system is supposed to take up its place from meridian to meridian, according to the local hour angle of the station, referred to the sun. A series of pins is inserted at the proper angles α, β, and if the force is acting downwards beneath the plane of the horizon the head is left on, and if above the plane of the horizon the pin head is removed, thus indicating the meaning of plus and minus α. The result shows that the ball is a conductor, that the forces enter upon the dark side of the earth and depart on the light side in the northern hemisphere, thus acting toward the sun, but the symmetrical plane of the field, as shown by the points of tangency and the inclination of the forces, is turned from the meridian supposed to represent the sun, so that a station reaches this plane before arriving at the meridian of the sun. We expect to explore this field of research fully, and only indicate the processes in this connection.

A few specimen results for a series of stations in June, 1883, are added to further illustrate this subject. After a study of the polar stations, bearing in mind the angles that the poles (ecliptic, geographical, magnetic) and the zenith of the various stations bear to each other, it will be seen that the action of a polarized conductor rotating in the field of the radiant sunlight regarded as a uniform magnetic field of force, is sufficient to explain clearly the variety of results that have been deduced. Instead of giving the magnetic azimuth β, the geographical azimuth is taken, A, counted from the north through the west.

TABLE VI.—*Stations with the diurnal deflecting forces that were in action during the month of June, 1883.*

Hours.	Fort Rae.				Point Barrow.				Kingua Fjord.				Jan-Mayen.				Bossekop.			
	σ	s	a	A	σ	s	a	A	σ	s	a	A	σ	s	a	A	σ	s	a	A
			°	°			°	°			°	°			°	°			°	°
Midnight......	49	50	—11	94	47	47	0	59	49	54	+25	49	63	65	+14	204	82	101	—36	169
2..............	47	78	+53	104	40	55	+43	94	46	58	+37	22	105	109	+15	226	90	116	—39	160
4..............	59	122	+61	152	58	97	+53	154	52	77	+48	346	127	129	— 9	241	51	78	—49	142
6..............	101	131	+39	179	116	155	+41	187	68	114	+53	302	94	116	—36	250	31	41	—40	122
8..............	115	116	+ 7	192	131	143	+24	201	97	129	+41	274	33	73	—63	259	19	26	—42	137
10..............	52	58	—26	219	62	63	—10	195	100	101	+ 7	267	14	62	—77	300	14	17	—34	203
Noon	15	32	—62	283	19	40	—62	101	73	107	—47	347	46	79	—54	30	26	29	+26	291
2..............	45	47	—17	346	30	46	—49	38	63	123	—59	176	95	121	—47	40	57	79	+44	336
4..............	90	94	—17	343	54	65	—34	12	78	122	—51	146	137	172	—37	43	80	118	+47	346
6..............	106	118	—26	344	79	90	—28	351	78	94	—34	122	98	163	—52	58	87	122	+44	347
8..............	72	92	—38	349	86	105	—35	340	87	88	— 8	95	63	128	—60	116	55	68	+36	339
10..............	34	63	—57	64	63	76	—34	3	76	77	+ 8	72	52	75	—46	169	23	33	—46	186
Midnight......	49	50	—11	94	47	47	0	59	49	54	+25	49	63	65	+14	204	82	101	—36	169

TABLE VI.—*Stations with the diurnal deflecting forces that were in action during the month of June,* 1883—Continued.

Hours.	Wilhelmshaven.				Pawlowsk.				Vienna.				Tiflis.				Zi-ka-wei.			
	σ	s	a	A	σ	s	a	A	σ	s	a	A	σ	s	a	A	σ	s	a	A
			°	°			°	°			°	°			°	°			°	°
Midnight...	8	13	+52	330	8	10	-38	338	9	9	+ 8	329	7	8	+29	314	14	14	+11	11
2...	6	7	+17	318	9	10	—40	292	10	11	+16	333	8	8	+22	292	20	21	+17	353
4...	16	17	+14	287	16	17	—16	282	13	14	+16	316	10	11	+22	298	35	36	+14	353
6...	32	32	+ 4	265	28	29	—11	265	29	30	+13	314	30	31	+11	271	50	53	+20	334
8...	30	33	—21	231	35	35	— 6	230	25	25	0	247	33	34	0	246	40	40	0	279
10...	34	38	—26	190	29	30	—11	191	23	25	—24	174	18	21	—31	189	25	36	—46	217
Noon.	36	48	—40	144	35	36	—11	134	30	35	—30	130	28	31	—26	89	23	34	—46	95
2...	36	50	—44	108	33	33	+ 4	98	35	36	—11	106	36	37	—12	76	34	36	—18	73
4...	24	25	+14	68	25	28	+26	51	21	21	+10	94	21	21	0	83	21	21	+15	121
6...	23	35	+50	24	20	25	+37	16	6	11	+56	20	5	10	+61	36	56	56	+ 6	180
8...	26	38	+47	358	19	21	+25	4	10	12	+31	359	2	6	+71	357	22	23	+17	174
10...	16	30	+59	351	14	14	— 7	356	13	13	+14	251	6	8	+39	341	11	11	+15	160
Midnight...	8	13	+52	330	8	10	—38	338	9	9	+ 8	329	7	8	+29	314	14	14	+11	11

We now pass to a table showing the method of comparing the magnetic with the meteorological elements.

TABLE VII.—*The meteorological deflections for the month of March*, 1889.

Date.	H	D	V	ΔH	ΔD	ΔV	*dx*	*dy*	*dz*	σ	s	α	β	D
		° ′			′							°	°	
		2 51.52												
1....	.198675	+70.01	.581232	− 94	+0.93	− 11	−123	+72	− 77	141	159	−28	150	
2....	731	69.39	216	− 38	+0.31	− 27	− 65	+35	− 89	73	115	−51	152	
3....	780	69.38	226	+ 11	+0.30	− 17	− 14	+34	− 75	35	82	−75	113	
4....	852	68.71	260	+ 83	−0.37	+ 17	+ 60	− 7	− 37	59	70	−31	352	
5....	836	68.44	302	+ 57	−0.64	+ 59	+ 36	−23	+ 9	42	43	+12	328	D_3
6....	727	69.69	298	− 42	+0.61	+ 55	− 61	+48	+ 10	77	77	+ 7	141	D_3
7....	733	68.75	325	− 36	−0.33	+ 82	− 53	− 8	+ 41	54	66	+36	190	D_1
8....	796	69.40	360	+ 27	+0.32	+117	+ 12	+29	+ 80	31	85	+69	69	
9....	796	69.32	317	+ 27	+0.24	+ 74	+ 13	+23	+ 41	25	47	+58	60	
10....	813	69.07	333	+ 44	−0.01	+ 90	+ 32	+ 8	+ 61	33	68	+62	15	
11....	861	69.14	342	+ 92	+0.06	+ 99	+ 82	+11	+ 75	82	109	+43	7	
12....	887	68.44	286	+118	−0.64	+ 43	+110	−31	+ 23	115	117	+10	344	D_2
13....	774	69.61	251	+ 5	+0.53	+ 8	− 1	+36	− 7	36	36	−10	91	D_2
14....	783	69.25	280	+ 14	+0.17	+ 37	+ 10	+14	+ 27	17	32	+56	55	
15....	809	69.05	282	+ 40	−0.03	+ 39	+ 38	+ 1	+ 39	38	55	+45	2	
16....	829	69.13	256	+ 60	+0.05	+ 13	+ 60	+ 4	+ 18	60	62	+17	2	
17....	658	69.32	325	−111	+0.24	+ 82	−110	+13	+ 97	111	153	+44	174	D_4
18....	702	68.66	221	+ 33	−0.42	− 22	+ 35	−28	+ 3	44	44	+ 2	320	
19....	783	68.56	209	+ 14	−0.52	− 34	+ 17	−35	+ 1	39	39	+ 2	293	
20....	747	69.15	257	− 22	+0.07	+ 14	− 18	− 3	+ 69	19	71	+74	184	
21....	775	69.84	238	+ 6	+0.76	− 5	+ 11	+36	+ 50	37	61	+54	73	
22....	722	68.33	283	− 47	−0.75	+ 40	− 41	−54	+105	67	124	+57	232	D_2.
23....	793	68.92	205	+ 24	−0.16	− 38	− 31	−20	+ 37	36	52	+42	213	D_2
24....	800	69.44	165	+ 31	+0.36	− 78	+ 39	+ 7	+ 7	40	40	+10	11	
25....	781	68.82	165	+ 12	−0.26	− 78	+ 21	−31	+ 17	37	41	+24	304	
26....	806	68.77	101	+ 37	−0.31	−142	+ 47	−36	− 37	58	68	−32	322	
27....	787	68.55	086	+ 18	−0.53	−157	+ 28	−50	− 42	58	71	−45	300	D_3
28....	644	68.68	091	−125	−0.40	−152	−113	−44	− 37	120	125	−17	202	D_3
29....	705	69.35	177	− 64	+0.27	− 66	− 51	− 7	+ 69	52	85	+54	190	D_1
30....	711	68.63	209	− 58	−0.45	− 34	− 44	−50	+111	66	128	+59	229	
31....	764	69.53	194	− 5	+0.45	− 49	+ 10	0	+106	10	106	+85	0	
	.198769	69.08	.581243											

TABLE VIII.—*The meteorological elements for the month of March, 1889.*

Date.	Barometer.	Thermometer.	Relative humidity.	Rain.	Clouds.	Wind.		Magnetic azimuth of the isobars.		
						Direction.	Force.	8 a.m.	8 p.m.	Mean.
	Inches.	°	*Per cent.*	*Inches.*						
1..	30.48	37.0	81	....	9	ne., w., se.	1	160	142	151
2..	30.26	39.5	86	0.17	10	se.	2	148	150	149
3..	29.99	40.5	92	0.88	10	s., ne., n.	4	112	120	116
4..	29.74	39.5	92	0.86	10	n.	8–12	345	350	348
5..	29.72	41.0	81	....	10	nw.	14	326	342	334
6..	29.54	41.5	56	....	2	nw.	13	180	188	184
7..	29.49	40.5	66	....	4	nw.	8	210	190	200
8..	29.67	38.3	59	....	2	nw.	9	40	40	40
9..	29.86	35.4	70	....	6	nw.	14	40	30	35
10..	29.96	34.8	68	....	9	nw.	12	15	10	12
11..	30.10	38.3	56	....	2	nw.	11	6	245	6–245
12..	30.09	44.5	61	....	0	nw., se.	1–3	290	310	300
13..	30.06	50.0	66	....	4	nw., se.	4	95	84	90
14..	30.15	47.1	72	....	9	ne.	10	60	44	52
15..	30.01	41.9	64	....	10	ne.	12	30	320	355
16..	29.88	44.5	70	....	10	ne., n., nw.	8	330	20	355
17..	29.87	51.3	60	....	5	nw., ne.	3	170	140	155
18..	29.90	47.5	76	0.21	6	nw., se.	3	330	310	320
19..	29.76	42.0	94	2.23	10	ne.	8	230	280	255
20..	29.76	40.0	83	1.00	10	ne.	10	295	130	212
21..	29.78	36.0	91	0.28	10	nw.	6	165	188	177
22..	30.17	44.0	70	....	9	nw.	6	225	210	218
23..	30.18	48.5	68	....	6	nw.	5	200	225	213
24..	29.94	52.3	64	....	7	nw., sw.	3	20	15	17
25..	29.67	52.0	77	....	10	n., se.	3	300	310	305
26..	30.05	41.2	57	....	1	se.	4	320	320	320
27..	29.94	53.3	74	0.03	4	se.	5	300	270	285
28..	29.90	45.0	65	0.03	9	sw., nw.	2–10	180	200	190
29..	30.07	47.7	54	....	2	nw., sw.	3–10	260	160	210
30..	30.35	36.0	60	....	0	nw.	13	210	00	210–0
31..	30.09	50.7	78	....	10	s.	12	350	350	350

The H, D, V are copied from the daily means for the month of March. ΔH, ΔD, ΔV are obtained by subtracting the mean value of the month from these daily means. The *dx*, *dy*, *dz* are derived from ΔH, ΔD, ΔV by applying the correction for the annual curve in the following manner: Since the mean for the month may be taken as the correct value of the H, D, V, for the middle of the month, by subtracting these monthly means in succession we obtain remainders to be distributed along the interval, in proportion to the time, the only error being in the assumption that the second difference may be neglected.

Thus we have for the intervals:

Intervals.	H	D	V
February and March	—58	+0.64	—131
March and April	—29	+0.91	—330

Half of these quantities are to be distributed from the beginning of the month, with the same sign forwards and with the opposite sign backwards, reducing them to zero by the middle of the respective months. Since ΔD is in minutes of arc it must be reduced to force, as explained above; σ, s, α, β are taken from the diagram scale. D_n represents the disturbance as noted on the photographic curves, D_1 indicating a mild disturbance, and D_4, the most severe found.

The meteorological elements are taken from the records of the U. S. Naval Observatory, by the permission of Professor J. R. Eastman, these numbers being the mean of eight three-hourly readings. The barometer and thermometer are also compared with the means of the barograph and the thermograph of the U. S. Weather Bureau, which is in the neighborhood, as a check. As all our work is purely differential, there is no need to pay special attention to absolute values in the magnetic or in the meteorological records, the relative changes alone being important.

The magnetic azimuth of the isobars is scaled off from the weather maps of the U. S. Signal Service for the month. It is only fair to remark that in reducing the azimuth to two readings for 8 a. m. and 8 p. m., we are comparing the mean magnetic azimuth β of a whole day with the mean of these two readings. A far better appreciation of the relation will be obtained by plotting the value of β upon the map itself, where it will be seen in its general relation to the whole set of isobars, and to the prevailing pressures about the highs and the lows. The comparison here indicated has been extended during each month for the three successive years 1889, 1890, 1891, and the persistence with which the relative changes follow each other in time precludes the possibility that the agreement is accidental.

At this time we refrain from discussing the meaning of these facts, because there are many physical conditions and relations involved which are not yet understood. It is seen by an attentive inspection

of the variations in the columns σ, s, α, β, that there are specially marked breaks in one or more of the terms, indicating a change in some of the magnetic stresses; in the same manner the barometer, thermometer, and relative humidity seem to vary rapidly in the same neighborhood, the commonest form being when the barometer reverses from falling to rising, the thermometer changes suddenly, and the relative humidity diminishes. Such breaks are indicated for the month of March by some dotted lines.

It will be observed that there is a decided tendency for the magnetic change to precede the meteorological by about one day, as if the magnetic influence being more sensitive felt the change before it came. It will also be noted that this magnetic change seems to occur when the rain center, which precedes the low barometer by several hours, is near at hand, or at least to be intimately related to that critical state of the atmosphere. Such a comparison as is here exhibited for March, 1889, has been carried out in full for the three years 1889–1891, and the number of coincidences, as well as the anticipatory relationship of the two sets of phenomena, persist throughout this period. It is intended to extend such a comparison to European magnetic and meteorological stations as rapidly as possible.

This comparison has been followed into its details by constructing a large monthly diagram of all the curves mentioned—humidity, barometer, thermometer, with appended data for the rain, clouds, and wind, also the declination, horizontal force, and vertical force. The meteorological curves are copied from self-registering instrument traces, and the magnetic curves from the traces given by the Kew instruments of the U. S. Magnetic Observatory, the two sets of apparatus being about 150 feet apart. All the traces are reduced to the same scale, four centimeters daily, the vertical ordinates being adapted to give clearly the relative changes on a similar vertical scale as seen by the eye. The points of the six-hour ordinates are plotted, also all the maxima and minima. A single sheet contains the continuous curves for a month. The traces for H and V were not corrected for temperature during October and November, but this correction has been applied to all that follow. Now a mean line is drawn through a series of middle points, counting successive maxima and minima points as the extremes for determining the mid-points, each curve thus having its mean curve.

If the month is blocked off into parts determined, for instance, by the intervals from one low to the next low, it is seen that both the meteorological and the magnetic mean curves tend to sway up and down once, that is, have but one inflection between such limits, and that the intensity of the meteorological conditions is responded to by the magnetic conditions. Furthermore, the amplitude of each of the magnetic traces rises and falls once during the interval indicated, showing that the passage of an atmospheric wave over a station is attended by an intensification and a relaxation of the magnetic deflecting forces.

DISTRIBUTION OF THE DEFLECTIONS.

We are thus brought to describe a device of interest, namely, a method for distributing the mean meteorological magnetic results just used in computation over the whole of the day, so as to obtain the meteorological effect at any given hour, freed from the diurnal and the disturbance effects. The question is, to what shall the photographic trace, with all its irregularities, be referred, in order at any given moment to measure out the meteorological residual. These traces sway up and down, as a whole, relatively to the base line, apart from the gradual change produced by loss of magnetism of the magnet, and from the changes in the coefficients by the temperature. The residuals ΔH, ΔD, ΔV, as derived from the printed page, being freed by computation from these sources of change, still represent that meteorological change as a mean value, but what we want is the twenty-four terms of which it is the arithmetical sum.

Our process is as follows:

The traces of the magnetic instruments of the Washington Observatory are so arranged that when looking at the curve as developed from left to right, beginning at about 12 o'clock noon and ending at the next 12 o'clock noon, in the H and D the base line is below the trace, but in V it is above the trace. The introduction to the volume, page 5, gives $+1$ millimeter ordinate $= +.000048$ C. G. S. units for H. F; $+1$ millimeter ordinate $= +1'.13$ westerly declination; and $+1$ millimeter ordinate $= -.000048$ C. G. S. units for V. F. Hence, laying the traces before us from left to right, in all cases of residual ordinates measured from the curve itself, above the curve means a positive change or increase in force, and below the curve a negative change or decrease in force.

We have constructed sets of normal scales for each month to facilitate our measurements. The material on which they are made is sheet celluloid, glazed on one side and rough on the other, the latter being peculiarly favorable for marking with common ink. The celluloid is cut in strips somewhat longer than the daily traces, scratched with three parallel lines two millimeters apart, there being three such groups, one for each of the H, D, V residuals. Upon these groups, counting from the middle line, is plotted, one for each hour at the proper distances corresponding to the automatic time breaks in the base line, the value of the residuals for the several hours, all in terms of millimeters. That is, the values of ΔH, ΔD, ΔV, as given in the computation of the diurnal deflecting curve, are changed to millimeters and rearranged in the following order:

Afternoon—March, 1889.

	12	1	2	3	4	5	6	7	8	9	10	11	12
H.....	−2.0	− .9	− .3	+ .8	+1.0	+ .8	− .1	+ .3	+ .4	+ .3	− .1	+ .4	+ .3
D.....	+1.7	+3.2	+3.2	+3.2	+2.3	+1.2	+ .7	+ .3	− .1	− .1	− .9	− .6	− .5
V.....	−1.4	− .9	− .6	− .1	0	+ .3	+ .6	+ .6	+ .8	+1.0	+ .9	+ .6	+ .3

Forenoon—March, 1889.

	12	1	2	3	4	5	6	7	8	9	10	11	12
H.....	+ .3	+ .3	+ .7	+ .3	+ .6	+ .8	+ .7	+ .8	0	−1.2	−2.1	−1.8	−2.0
D.....	− .5	− .8	− .4	− .7	−1.0	−1.1	− .9	−1.8	−2.8	−3.0	−2.2	− .2	−1.7
V.....	+ .3	− .1	− .3	− .3	+ .4	+ .1	+ .2	+ .3	+ .2	− .1	− .6	−1.3	−1.4

The resulting scale for March consists, therefore, of a succession of dots one hour apart, following the normal diurnal curve of the month in H, D, V. A second scale is copied from the first by dotting in the points as superposed, only in the second scale the parallel lines are omitted.

Having thus obtained the normal scale, the problem is to apply it to any day of the month. This scale is most accurate for the middle of the month. If another be formed for the adjacent months, February and April, these will differ a little from the scale for March, by as much as the diurnal curve of one month deviates from its neighbor, and evidently, by proportion, a series of scales can be formed of accurate application to any given day. This would be too great a refinement for our purpose just now, and we use the March scale throughout the month. If the curve for any day were unaffected by causes other than those which produce the diurnal curve, then the trace would agree closely with the curve just constructed. But wishing to eliminate this ideal curve from the annual, the meteorological, and the disturbance deflections, our method is as follows:

Corresponding to any given hour for each day of the month, according to the printed page, there is a computed value of absolute measure in H, D, V to which that ordinate corresponds. If from the final means of the month (in the corner of the pages) a value of the annual curve be computed by plotting on a diagram and reading off the values for the intermediate dates, and then to each of these values, one for each day, the mean diurnal values for the month be added, the normal diurnal values for that day are obtained, that is, those several values which the undeflected daily traces should have read. By subtracting the actual readings as printed, from these values as computed, we obtain residual corrections to the traces to find the normal diurnal curve. Thus we can plot down normal points on the trace sheets, and then by applying the scales to a few of these points, say three for each day, the true normal position of the undeflected trace stands before us, with which the actual trace can immediately be compared. For example, here is given the complete computation for H and the results of similiar processes for D and V:

TABLE IX.—*Deflection differences from the traces to the normal diurnal curves H, D, V.*

Date.	Annual H.	12 o'clock noon.	Residual.	Corrected value.	Difference.	12 o'clock midnight.	Residual.	Corrected value.	Difference.	H		D		V	
										12 noon.	12 midnight.	12 noon.	12 midnight.	12 noon.	12 midnight.
1	.198795	.198670	−99	.198696	− 26	.198729	+15	.198810	− 81	− .5	−1.6	− .2	+ .8	−3.1	−1.5
2	793	605		694	− 89	787		808	− 21	−1.8	− .4	+ .4	+ .7	−2.7	−2.1
3	791	611		692	− 81	845		806	+ 39	−1.6	+ .8	− .3	+1.8	−2.8	− .8
4	789	805		690	+115	921		804	+117	+2.3	+2.4	0	+ .1	+ .1	−1.4
5	787	890		688	+202	658		802	−144	+4.1	−2.9	− .9	−2.5	0	+1.1
6	784	652		685	− 33	594		799	−205	− .7	−4.1	[+5.7]	−4.1	+ .6	+ .1
7	782	611		683	− 72	755		797	− 42	−1.5	− .8	−1.1	+ .2	+ .9	+1.8
8	781	649		682	− 33	793		796	− 3	− .7	− .1	+1.6	+ .5	+ .9	+ .9
9	780	683		681	+ 2	851		795	+ 56	0	+1.1	+ .5	+ .6	0	+ .9
10	778	651		679	− 28	838		793	+ 45	− .6	+ .9	− .5	+ .1	+ .8	+1.0
11	777	713		678	+ 35	866		792	+ 74	+ .7	+1.5	+ .2	− .1	+2.4	+ .8
12	776	752		677	+ 75	849		791	+ 58	+1.5	+1.2	− .7	− .1	0	− .5
13	774	833		675	+158	624		789	−165	+3.2	−3.3	−1.5	+ .3	− .1	+1.8
14	772	684		673	+ 11	889		787	+102	+ .2	+2.1	+ .7	− .2	+3.0	− .2
15	771	679		652	+ 7	828		786	+ 42	+ .1	+ .9	+ .2	− .8	+1.6	+ .1
16	770	669		671	− 2	895		785	+110	0	+2.2	+ .8	− .1	+1.4	+1.2
17	769	825		670	+155	595		784	−189	+3.1	−3.8	+ .9	−4.8	− .6	+1.6
18	768	....		669	[−101]	789		783	+ 6	[−3.7]	+ .1	+ .9	−1.3	+ .2	− .5
19	767	691		668	+ 23	804		782	+ 22	+ .5	+ .5	− .9	+ .4	+ .3	+ .6
20	766	655		667	− 12	753		781	− 28	− .2	− .6	− .9	+ .4	+1.7	+1.6
21	765	552		666	−114	905		780	+125	−2.3	+2.5	+1.2	+ .3	+ .2	+2.0
22	764	581		665	− 84	793		779	+ 14	−1.7	+ .3	+ .8	+ .1	+1.9	+1.9
23	762	761		663	+ 98	784		777	+ 7	+2.0	+ .2	−1.1	0	+1.2	− .4
24	761	649		662	− 13	842		776	+ 66	− .3	+1.3	− .1	+2.3	− .1	+1.0
25	760	697		661	+ 36	824		775	+ 49	+ .7	+1.0	− .2	+ .2	+ .5	−1.1
26	759	750		660	+ 90	....		774	[− 58]	+1.8	[−1.2]	+1.2	[o]	−1.2	[− .9]
27	759	793		660	+133	643		774	−131	+2.7	−2.6	+ .1	−3.1	− .7	−5.6
28	758	498		659	−161	625		773	−148	−3.2	−3.0	+4.1	− .3	−2.9	+1.5
29	757	368		658	−290	847		772	+ 75	−5.8	+1.5	+3.5	− .5	+ .7	+ .2
30	756	509		657	−148	806		771	+ 35	−3.0	+ .7	−2.1	+ .3	+3.4	+2.9
31	756	628		657	− 29	797		771	+ 26	− .6	+ .5	+ .5	+ .2	+1.6	+1.0

The column "annual H" gives the value of the horizontal force for March as taken from the plotted curve; 12 o'clock noon and 12 o'clock midnight are copied from the absolute values of H for these hours; "residual" means the ordinate of the diurnal deflection curve for the respective hours, and it is applied as a correction to annual H to give the "corrected value;" the "difference" is obtained by subtracting the "corrected value" from the "12 o'clock" readings; under H, D, V occur the corresponding residual ordinates in millimeters. Similar residuals can be found for any other hours; where bracketed values occur, the next preceding hour was taken, in case the 12 o'clock values are missing for any reason.

The curves on the sheets are next gone over, and dots are placed above or below the magnetic trace to show for at least three points each day where the normal curve ought to have been located, and by matching these points and the corresponding points on the scale we see the relation between the given curve and the theoretical curve. Having thus practically eliminated the annual and the diurnal deflections, what remains is to be attributed to the meteorological and the disturbance deflections. It is seen, (1) that the daily curves tend to sway up and down on either side of the theoretical curve, this being the meteorological effect, (2) that the disturbances are superposed upon the meteorological trace; hence these are to be separated.

The second dotted scale is taken, disregarding now all our previous processes, and it is laid upon the daily trace so as to match as perfectly as possible its course throughout the day, this on some days being a simple matter. The position of this scale is indicated by dashes at each end of the day, and evidently the dashes will be separated from the dots set there by the previous work, according to the trend of the curve. The end dash of one day is transferred to the beginning of the following day, at the same distance from its dot, and this forms the starting point or pivot for one end of the scale, which has to be swung upon the day's curve by best judgment.

In this way each day's dashes are made to depend mutually upon the preceding and the following day, as well as upon the curve itself, and it is surprising how much accuracy of setting the scale can be attained in spite of the many irregularities of the curve, because there are in the course of the three days certain parts which are normal so far as the disturbances are concerned. We take the liberty of recommending this treatment of observations, because it goes to the bottom of the matter, at least so far as the specific disturbances are concerned.

Next, the two scales are set simultaneously over the dots and the dashes, and, being transparent, the curve and the two sets of dots on the scales can be seen all together. By reading off the differences between the two sets of dots or the first normal dots and the curve itself, when the curve runs closely to the dots of the second scale, we have the meteorological residual ordinates by themselves, freed from the annual,

the diurnal, and the disturbance residuals. Thus have we distributed throughout the day the meteorological mean residuals which have already been used.

Short example of meteorological residuals between two scales.

AFTERNOON.

March.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Midnight.
1	−2.3	−2.2	−2.1	−2.0	−1.9	−1.8	−1.7	−1.5	−1.3	−1.2	−1.0	−0.9	−0.7
2	+1.0	+0.9	+0.8	+0.7	+0.5	+0.3	+0.2	+0.1	0.0	0.0	−0.1	−0.1	−0.1
3	−1.2	−1.2	−1.0	−0.8	−0.6	−0.4	−0.2	0.0	+0.2	+0.4	+0.6	+0.8	+1.0
4	+3.4	+3.3	+3.2	+3.1	+3.0	+2.9	+2.8	+2.8	+2.8	+2.7	+2.7	+2.7	+2.7
5	+2.5	+2.4	+2.2	+2.0	+1.9	+1.8	+1.7	+1.6	+1.5	+1.3	+1.1	+1.0	+0.9

FORENOON.

March.	Midnight.	1.	2.	3.	4.	5.	6.	7.	7.	9.	10.	11.	Noon.
1	−0.7	−0.5	−0.3	−0.1	0.0	0.0	+0.2	+0.3	+0.4	+0.6	+0.8	+0.9	+1.0
2	−0.1	−0.2	−0.2	−0.2	−0.3	−0.4	−0.5	−0.7	−0.9	−1.0	−1.1	−1.1	−1.1
3	+1.0	+1.2	+1.4	+1.6	+1.8	+2.0	+2.2	+2.4	+2.6	+2.8	+3.0	+3.2	+3.4
4	+2.7	+2.6	+2.6	+2.6	+2.6	+2.5	+2.5	+2.5	+2.5	+2.5	+2.5	+2.5	+2.5
5	+0.9	+0.7	+0.5	+0.3	+0.1	0.0	0.0	−0.1	−0.2	−0.3	−0.4	−0.5	−0.6

By careful management of these scales there can be made a very useful set of reference curves, from which even minute studies into the changes that are continuously going on can be prosecuted, and as these are deflecting forces depending upon existing physical conditions, it will assist greatly in the solution of all the allied problems.

ORIGIN OF THE DISTURBANCES.

I can give one striking illustration of this fact in regard to the origin of the disturbances that have been so long under consideration. By matching one dotted scale to the curve, as above suggested, it is seen that on certain days, for several consecutive hours the trace is swept away from the dots in a pronounced manner, during periods of disturbance. Now, measuring off the residual disturbance ordinates, and combining them as in the other cases, we find the s, α, β corresponding to them, that is, the force, and the direction from which it came, that effected the displacement of the curve. Having computed about twenty such periods of disturbance, obtained the coördinates of the deflecting force, transferred them to another ball with pins, it is seen that instead of coming from all quarters in space, they originate in three directions, one perpendicular to the plane of the ecliptic, one towards the sun, and one in the direction of the orbital motion of the earth. These directions are all of them modified, as they should be, for the curvature of the lines of force, as if the earth were an absorbing conductor in uniform fields; and because the earth is rotating in these fields, the radiant and the orbital fields show the accompanying retardation in a complete manner. This distribution may be regarded

as a case of magnetic refraction, and as the analytical solution of the conditions is extremely difficult, this may be the best way to secure a practical set of formulæ. Unless further computations produce conflicting evidence, these facts must be taken as testimony of great importance in regard to our general view of the subject in its cosmical relations. An example from each of these three fields is appended. The disturbance residuals are so large, in reference to the margin of doubt in setting the scale (that is, one-half a millimeter), as to admit of no question as to the meaning of the results.

Disturbance of March 17–18, 1889, *originating in the coronal field.*

Hours.	dx	dy	dz	s	a	β	Hours.	dx	dy	dz	s	a	β
					°	°						°	°
3 p. m....	+ 100	+ 23	+ 10	104	+ 4	13	9 p. m...	−900	− 98	+400	990	+24	186
3·30......	+ 200	+ 40	+ 50	212	+14	12	9·30.....	−650	−139	+350	756	+28	192
4.........	+ 450	+ 35	+ 60	432	+ 8	3	10.......	−425	−116	+275	516	+33	195
4·30......	+ 100	+127	+140	194	+41	38	10·30....	−450	00	+200	488	+24	180
5.........	0	+156	+200	254	+52	90	11.......	−390	+116	+210	456	+26	162
5·30......	− 200	−104	+310	370	+57	207	11·30....	−180	+173	+115	276	+26	126
6.........	− 450	−347	+60c	828	+47	218	12 a. m...	−325	−266	+ 85	436	+12	219
6·30......	− 525	+104	+550	762	+46	168	12·30....	−350	−197	+ 50	412	+ 6	209
7.........	−1100	+133	+450	1130	+23	173	1........	−175	− 98	+105	228	+27	210
7·30......	− 850	+185	+430	978	+64	168	1·30.....	−185	− 58	+115	228	+31	198
8.........	− 700	+145	+550	912	+37	169	2........	−200	− 47	+275	346	+53	194
8·30......	− 650	− 81	+45c	738	+34	187							

Disturbance of April 7–8, 1889, *originating in the orbit field.*

Hours.	dx	dy	dz	s	a	β	Hours.	dx	dy	dz	s	a	β
					°	°						°	°
8 p. m....	+ 30	− 58	+ 10	67	+ 9	297	2 a. m...	+160	− 58	−275	326	−58	340
8·30......	−115	−139	+ 65	192	+20	231	2·30.....	+ 35	−405	−295	504	−36	276
9.........	−300	−278	+ 85	402	+13	222	3........	− 65	−682	−310	750	−24	264
9·30......	−365	−491	+ 75	618	+ 7	234	3·30.....	−240	+260	−285	459	−38	227
10........	−780	−780	+ 30	1108	+ 3	225	4........	− 75	+173	−215	288	−49	114
10·30.....	−670	−434	+ 25	800	+ 3	213	4·30.....	0	+ 12	−155	156	−86	90
11........	−215	−116	+ 90	266	+19	208	5........	− 55	−104	−120	168	−45	242
11·30.....	−200	−289	+ 75	362	+13	235	5·30.....	− 75	− 70	− 45	113	−23	223
12 a. m...	−135	−129	+110	226	+29	226	6........	− 90	− 58	− 35	113	−18	213
12·30.....	+ 15	− 58	+ 45	77	+35	284	6·30.....	− 20	− 47	− 10	53	−11	247
1.........	− 75	− 35	− 20	85	−13	205	7........	− 75	− 35	− 15	84	−11	205
1·30......	−165	+ 58	−225	288	−52	199							

Disturbance of September 22, 1889, *originating partly in the radiant field.*

Hours.	dx	dy	dz	s	a	β	Hours.	dx	dy	dz	s	a	β
					°	°						°	°
4 a. m....	+ 80	0	− 15	82	−11	0	10 a. m...	−365	+ 23	− 50	372	− 8	176
4·30......	+ 65	− 47	− 10	81	− 7	323	10·30....	−325	+202	− 60	386	− 9	148
5.........	0	−150	− 15	152	− 5	270	11.......	−480	+191	− 65	528	− 7	158
5·30......	− 50	−127	− 20	139	− 8	248	11·30....	−350	+364	− 50	515	− 6	134
6.........	− 15	− 75	− 30	84	−22	258	12 noon..	−100	+116	− 50	162	−18	132
6·30......	−280	+ 87	− 40	298	− 8	163	12·30 p.m	+ 90	+ 37	− 55	138	−24	44
7.........	+250	+341	− 60	428	− 7	54	1........	− 50	+277	− 45	288	− 8	100
7·30......	+270	+ 58	− 60	286	−13	12	1·30.....	−200	+214	− 30	296	− 7	133
8.........	+160	+ 17	− 60	171	−21	6	2........	−140	+116	− 30	368	− 6	140
8·30......	+100	0	− 65	119	−33	0	2·30.....	+160	+133	− 20	45	−26	104
9.........	+140	+156	− 45	223	−23	48	3........	−150	+110	− 10	186	− 3	144
9·30......	+ 50	+ 58	− 35	85	−24	50	3·30.....	−160	+ 93	00	186	0	150

The coronal field is most clearly defined, the direction of the forces being persistent, and the whole field exhibiting activity throughout the twenty-four hours. By introducing this force into the formulæ, already given in previous papers, some knowledge of the originating forces at the surface of the sun may be computed; also by studying these disturbances we shall have a more sensitive guide to the fluctuations of the solar forces than has been gained through observations of the sun spots, faculæ, etc.

The orbital field is more of a mystery. It exists only on the dark side of the earth, and shows some diversity of direction, arising from the fact, probably, that it is a weaker field, which, if originating in induction at the surface of the earth, as is likely, is subject to more conflicting impulses. It is thrown backward about 23° by the rotation of the earth on its axis, and in some parts of it the forces are parallel to each other, even when derived from dates that are months apart.

The radiant field is the least important of the three, and it may not be a true disturbance field of itself, but only a reassertion of the deflections that produce the diurnal variations. At certain local hour angles there is seen a conflict between these different fields, depending upon the relative strength of those in action, and this is evident by the uncertainty of direction among the pins representing these forces. Such hours may be mentioned at 3 p. m.–5 p. m. and 5 a. m.–7 a. m., that is, along the places where the radiant magnetic field falls tangent to the surface of the earth.

On January 5, 1892, there was registered at the Washington Magnetic Observatory the impulses of a strong magnetic disturbance. Upon applying to the traces the analysis and the computations described above, it appeared to exhibit so excellent an example of some of the conclusions stated in this paper that the data and illustrations of it are now given.

The traces of H, D, and V are copied directly from the magnetograph curves. They begin at 12 o'clock noon January 5th and extend to the following midnight. The forces concerned in producing these impulses are so strong that the direction in space from which they came must be regarded as well determined. The total magnetic force of the earth's field at Washington being taken as 0.61400 C. G. S. units, the maximum deflecting force imposed upon it was about 0.00250 C. G. S., or one two hundred and forty-sixth ($\frac{1}{246}$) of the permanent field. The resulting deflecting forces when transferred to a globe placed in the approximate astronomical position occupied by the earth for January 5, show clearly the presence of two magnetic fields, one directed towards the sun, undergoing the usual magnetic refraction belonging to the diurnal variations, as already indicated; the other, and this the true disturbance field, perpendicular to the plane of the ecliptic. At certain points the inter-play between these two fields is shown, but

the marked character of the direction of the forces cannot be disregarded. The field perpendicular to the ecliptic occurs from 12 noon to 3.20 p. m., from 5 p. m. to 6.40 p. m., and from 8 p. m. to 10 p. m. On the sunny side of the earth the direction is from south to north, on the dark side from north to south, indicating an oscillation in opposite directions along the same line. The diurnal field occurs from 3.40 p. m. to 5 p. m. and from 7 to 7.30 p. m., according to the regular system. From 10.30 p. m. there sets in another field on the dark side of the earth.

It seems then that the existence of the two fields, one parallel, and the other perpendicular, to the ecliptic, the former continuously acting and the other spasmodic in its operation, can hardly be doubted. The treatment of the problem thus developed has the merit of wholly eliminating the action of the permanent magnetism of the earth from the data, leaving us free to discuss the disturbances and variations as an independent topic.

Disturbance of January 5, 1892.

Time.	ΔH	ΔD	ΔV	*dx*	*dy*	*dz*	σ	*s*	α	β	Remarks.
									°	°	
12......	+ 5.9	− 0.9	− 1.8	+ 266	− 58	− 148	272	310	−28	348	Perpendicular to the plane of the ecliptic.
12.30...	+ 6.2	− 1.0	− 2.0	+ 279	− 66	− 164	287	331	−29	351	
1.......	+ 5.8	− 3.9	− 2.0	+ 261	− 255	− 164	365	400	−25	315	
1.30....	+12.7	− 2.2	− 2.2	+ 572	− 144	− 180	590	617	−17	346	
2.......	+10.7	− 2.7	− 2.9	+ 482	− 176	− 238	513	544	−25	340	
2.30....	+12.4	− 0.4	− 2.5	+ 553	− 26	− 205	554	603	−20	358	
3.......	+ 9.2	− 0.8	− 3.0	+ 414	− 52	− 246	417	484	−31	353	
3.20....	+13.8	+ 0.8	− 2.8	+ 621	+ 52	− 230	623	664	−21	4	
3.40....	0.0	+ 3.8	− 2.0	0	+ 248	− 164	248	297	−34	90	Parallel.
4.......	− 6.8	+ 4.9	− 1.7	− 306	+ 320	− 139	443	464	−17	134	
4.30....	− 1.6	+ 0.8	− 1.6	− 72	+ 52	− 131	89	158	−56	144	
4.40....	0.0	+ 0.6	− 1.6	0	+ 40	− 131	40	137	−73	90	
5.......	+ 4.1	+ 0.6	− 1.4	+ 185	+ 40	− 115	189	221	−32	12	Perpendicular.
5.30....	+ 4.6	+ 1.3	− 1.4	+ 207	+ 85	− 115	224	252	−29	23	
6.......	+ 6.4	+ 2.0	− 1.9	+ 288	+ 131	− 156	316	352	−26	24	
6.20....	+11.1	+ 1.0	− 1.5	+ 500	+ 66	− 123	504	519	−14	6	
6.40....	+ 6.0	+ 5.0	− 1.2	+ 270	+ 327	− 98	424	435	−13	50	
7.......	+ 0.3	− 4.0	+ 4.7	+ 14	− 262	+ 385	262	466	+56	273	Parallel.
7.20....	+ 8.4	+ 9.6	+ 3.7	+ 378	+ 627	+ 303	732	792	+23	59	
7.25....	0.0	+ 7.0	+ 4.0	0	+ 458	+ 328	458	563	+35	90	
8.......	−15.0	−12.0	+11.2	− 675	− 784	+ 918	1035	1383	+42	229	Perpendicular.
8.30....	−14.0	−18.6	+13.0	− 630	−1215	+1066	1369	1735	+38	243	
9.......	− 6.7	− 2.0	+16.2	− 302	− 131	+1328	329	1369	+76	204	
9.20....	−30.0	−19.0	+19.7	−1350	−1241	+1615	1834	2444	+43	222	
10......	−11.0	−27.2	+10.6	− 495	−1777	+ 869	1845	2039	+26	255	
10.20...	−14.0	+11.0	− 8.0	− 630	+ 719	− 656	956	1159	−34	132	Parallel.
10.40...	− 5.6	+ 4.0	− 7.0	− 252	+ 261	− 574	363	679	−58	134	
11......	− 9.4	− 4.0	− 2.3	− 423	− 261	− 189	497	532	−22	212	
11.30...	− 8.0	− 5.2	− 1 2	− 360	− 340	− 98	495	505	−12	222	
12......	− 7.7	− 2.0	− 0.5	− 347	− 131	− 41	371	373	− 6	196	

ΔH, ΔD, and ΔV are millimeters measured from the dots which represent the normal diurnal curve.

dx, *dy*, *dz* are derived by the following constants:

H, 1 millimeter = .000045 C. G. S. units;

V, 1 millimeter = .000082 C. G. S. units;

D, 10′ = 8.86 millimeters.

σ, s, α, β are computed by the formulæ,

α, the altitude of the deflecting force from the horizon,

β, the azimuth of the same from the magnetic meridian in the direction n., w., s., e.,

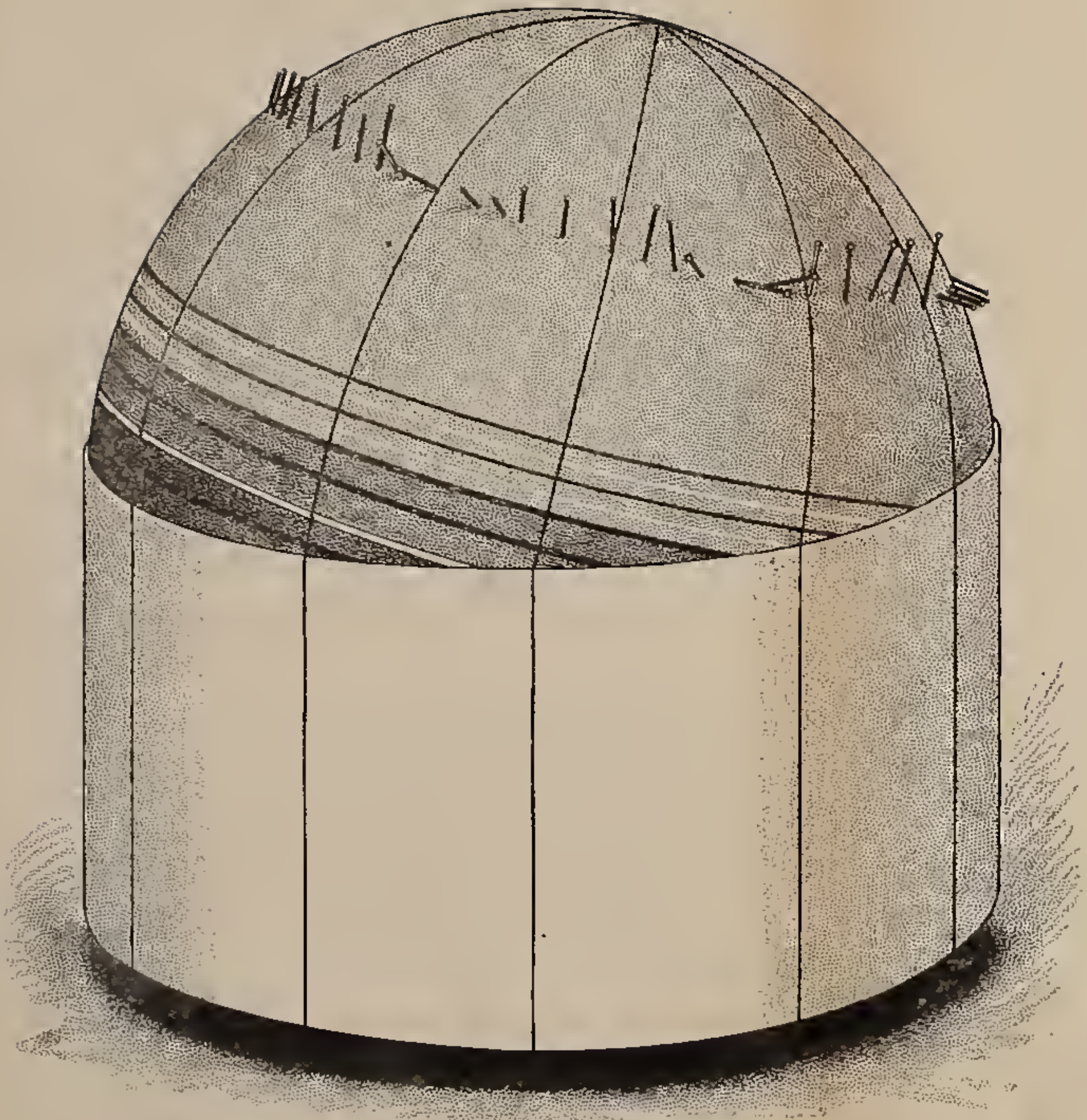
s, the deflecting force, in units of the fifth decimal place.

The globe is viewed from a point in the ecliptic opposite the six-hour circle, counted from noon, and is seen to represent its approximate position for January 5.

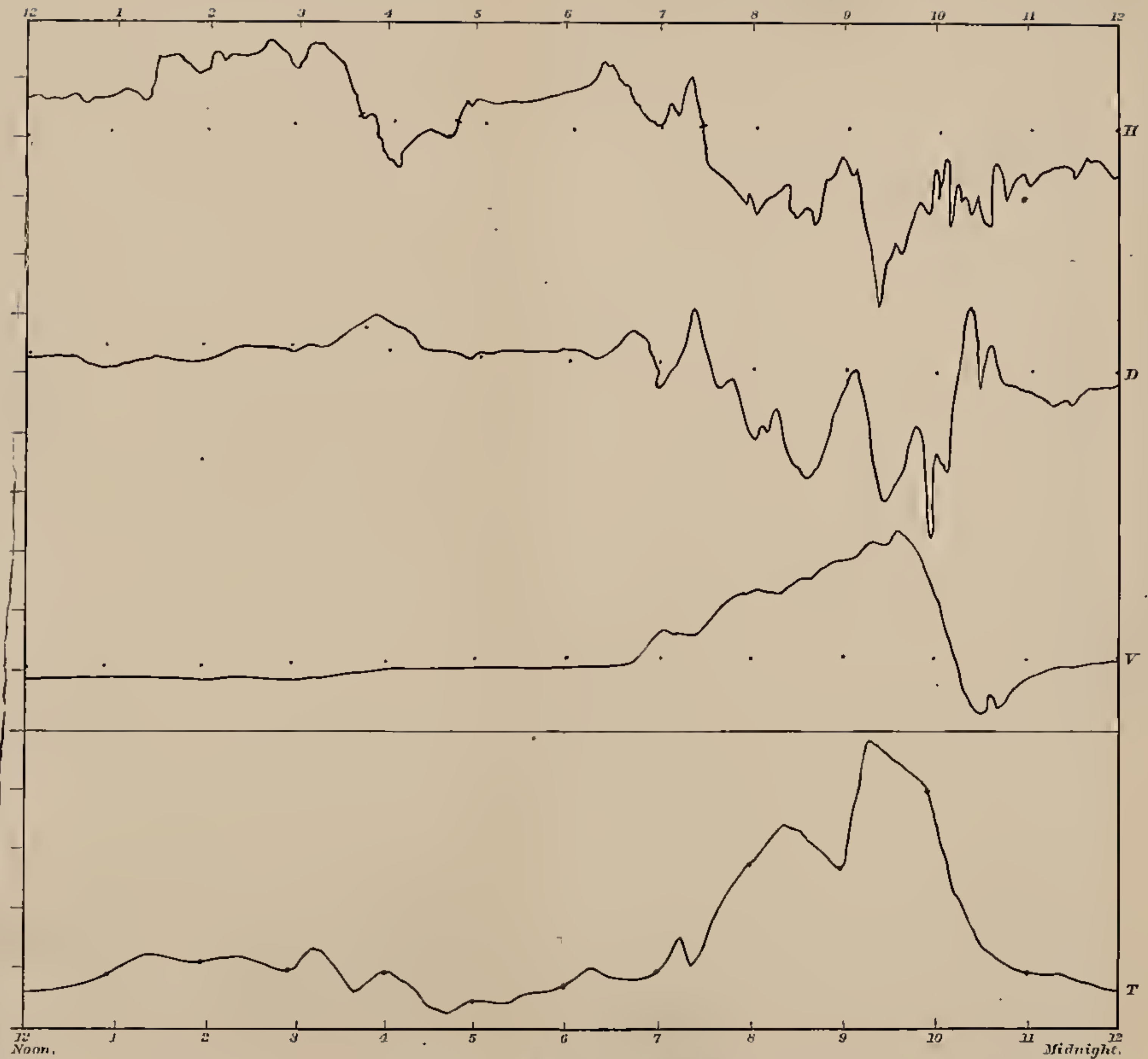
There is another method of accounting for the deflecting forces which act during the disturbances, so far as concerns their directions. The radiant field on entering the earth through its peculiar curvature divides itself into two portions, one characteristic of the polar regions, and defined by the action of a magnet nearly at right angles to the direction of the field; the other characteristic of the lower latitudes, and specified as simply a case of magnetic refraction. Now, when the solar energy intensifies, the radiant field in transmitting this energy strengthens and spreads the true polar field downwards over the normal low latitude field temporarily, so that during disturbances we have an alternate action of these two fields.

Thus, in the illustration, the first eight pins on the left belong to the polar field on the light side of the earth, and act upwards; the next four pins are where the disturbance force is lessened and the normal emergent field by refraction resumes its supremacy; then we have four more pins where the polar field is again intensified; next there are three pins where the entering forces of the radiant field appear, and are really continuous with the four forces of the radiant field just described; then come five pins with heads on, standing for the forces of the polar field on the dark side of the earth, which, in this case, must act downwards; finally, the four sharp pins represent the increased activity of the normal terrestrial field, which, at this latitude, has a dip of about 71°, and which may express the energy impressed upon the total permanent system of the earth by the antecedent stages of the induction. The peculiar distribution is such as to be referred with equal probability to either the coronal or the radiant fields, but it will be necessary to undertake a more extensive discussion of the systems of disturbances before this can be finally settled.

WASHINGTON, D. C., *April* 22, 1892.



Model showing the deflecting forces in the disturbance of January 5, 1892.



Disturbance of January 5, 1892, Washington, D. C.